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New trends in Industrial Energy Efficiency in the Mexico: Iron and Steel Industry

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ABSTRACT

Energy use in the Mexican industrial sector experienced important changes in the last decade related to changes in the Mexican economy. In previous studies, we have showed that a real change in energy-intensity was the most important factor in the overall decline of energy use and CO_2 emissions in the Mexican industrial sector. Real changes in energy intensity were explained by different factors, depending on the industrial sub-sector. In this paper, we analyze the factors that influenced energy use in the Mexican iron and steel industry, the largest energy consuming and energy-intensive industry in the country. To understand the trends in this industry we used a decomposition analysis based on physical indicators to decompose the changes in intra-sectoral structural changes and efficiency improvements. Also, we use a structure-efficiency analysis for international comparisons, considering industrial structure and the best available technology. In 1995, Mexican iron and steel industry consumed 17.7% of the industrial energy consumption. Between 1970 and 1995, the steel production has increased with an annual growth rate of 4.7%, while the specific energy consumption (SEC) has decreased from 28.4 to 23.8 GJ/tonne of crude steel. This reduction was due to energy efficiency improvements (disappearance of the open hearth production, increase of the share of the continuous casting) and to structural changes as well (increase of the share of scrap input in the steelmaking).

I. INTRODUCTION

In 1995, the Mexican iron and steel industry produced 12.1 Mt of crude steel, which represented the 1.6% of the world production. It was the 16th largest crude steel producer in the world (ILAFA).

The history of the Mexican iron and steel industry began in 1903 with the construction of the first integrated plant of *Fundidora de Monterrey* (Fumosa). To satisfy the increasing demand of steel in the late 1940s this plant was modernized developing its own technology HYL to produce direct reduced iron; From the 1940s to the 1980s, the Mexican Government supported the growth of the iron and steel industry by subsidies, financial incentives, duties protection, etc. In 1977, the State organized and managed AHMSA (Fumosa and SICARTSA as an associated group called Sidermex) to optimize their productivity. Although this association, the Fumosa plant closed in 1986 due to its improductivity. Some years later the privatization of the state-owned companies began, and it was complete in the end of 1991. Since then, investment in expansion and modernization of the iron and steel integrated plants has grown and it is expected that it will continue until 2000 (Baro, 1997). From 1986 to 1996, the installed capacity of the secondary steelmaking plants (mini mills) increased from 1.6 to5.7 Mtonnes in 1996 (Pemex, 1985; I&M, selected years).

Between 1970 and 1995 Mexican steel production increased with an annual growth of rate of 4.7%, while the SEC of this industry decreased 16.1%. To analyze the main driving forces of these changes and to evaluate the energy efficiency technical potential, we followed the International Network for Energy Demand Analysis in the Industrial Sector (INEDIS) methodology (Phylipsen, et.al., 1998).

This paper is divided in five sections. After the introduction we summarize the iron and steel manufacturing process, then we describe the methodology to analyze decomposition of trends and international comparisons. The following section gives an overview of Mexican iron and steel energy consumption. Section five presents results of the SEC decomposition analysis as well as international comparisons. Finally we present the conclusions.

II. METHODOLOGY

Following the recommendation of the International Comparisons Methodology Handbook (1998), we used physical unit as the activity and specific energy consumption indicator. A decomposition analysis based on this variable was used to distinguish the changes in intra-sectoral structure and in efficiency improvements. Finally a comparison of the actual SEC relative to a "best practice" reference plant was used to estimate the potential of energy efficiency improvement of the Mexican Iron and Steel industry and to recommend energy efficiency measures.

II.1. Decomposition trends in the Mexican Iron and Steel Industry

To understand the factors that influence the energy consumption in the Mexican Iron and Steel industry, we used a decomposition methodology proposed by Farla, et.al (1997). The total energy consumption of this industry is function of the production volume (activity), the process and product mix (structure) and the energy efficiency of the production processes. However, we used a physical production index (PPI) because the composition of the production changes with time and differs by country. Instead of a simple summation of the total industry output, the production of each steel product is weighted by a weighing factor.

$$PPI = \sum_{i=1}^{n} (P_i \cdot SEC_{BP_i}) \qquad (1)$$

The weighing factors are based on the energy consumed to produce each steel product using the existing best practice (Table 1).

According to the definition described above and taking into account the PPI, the total energy consumption can be calculated as

$$\sum E = \sum P \cdot \frac{PPI}{\sum P} \cdot \frac{\sum E}{PPI} \qquad (2)$$

where the simple summation of the different products ΣP is the parameter of activity; the structure parameter is given by $PPI/\Sigma P$ and the energy efficiency parameter of the production processes is given by $\Sigma E/PPI$.

With the index decomposition, the influences of changes in the activity, in the structure or process mix, and in the efficiency on the total energy consumption can be calculated between year 0 and year T as following:

$$\Delta E_{0,T} = \Delta E_{0,T(act)} + \Delta E_{0,T(struc)} + \Delta E_{0,T(eff)} + R \qquad (3)$$

where R is a residual term. According to the classification of Ang (1995), we used an additive energy intensity technique and a Laspeyres-based parametric Divisa method 2 (LAS-PDM2) to analyze the factors that contribute to the decrease in the SEC of the Mexican Iron and Steel industry.

. **Table 1. Best practice SEC for different processes in the Iron and Steel Industry**

Process	Best practice SEC_f [GJ_f/tcs]	Best practice SEC_e [GJ_e/tcs]	Best practice SEC_p [g] [GJ_p/tcs]
BF[a]	15.19	0.26	15.98
DRI[b]	11.19	0.17	11.71
BOF+casting[c]	0.57	0.12	0.93
EAF+casting[d]	0.79	1.52	5.4
Hot strip mill[e]	1.82	0.37	2.94
Cold rolling mill[f]	1.1	0.53	2.71

[a] The SEC of the blast furnace process considers the iron ore preparation of an integrated plant of the Netherlands in 1988, assuming a blast furnace feed of 50% pellets and 50% sinter (Worrell, et. al., 1997b) [b] The SEC of the direct reduction process considers pellet preparation and it is based on a HYL plant of Mexico (McAloon, 1993) [c] The SEC of the BOF process and continuous casting is for a integrated plant of the Netherlands in 1988 (Worrell, et.al., 1997b) [d] The SEC of the EAF and continuous casting is considered for a plant in Germany (Worrell, et. al., 1997) [e] The SEC of a hot strip mill of an integrated plant at the Netherlands in 1988 (Worrell, et.al., 1997) [f] The SEC of a cold rolling mill at an integrated plants in the Netherlands (Worrell, et. al., 1997) [g] Assuming an electricity generation efficiency of 33%.

II. 2 International Comparison structure/efficiency methodology

According to the International Comparisons Methodology, the SEC is influenced by the process and product mix, ie the feedstock used in the process (iron ore and scrap for the primary steel or only scrap for the secondary steel) and the type of products (slabs, sheets, bars, billets, etc.) and by the efficiency of the manufacturing processes (Phylipsen, et.al., 1998).

In order to understand the contribution of these factors in the decrease of the SEC and to compare the SEC for different countries, the International Comparisons methodology recommends to illustrate the SEC as a function of the changes in product mix (structure) and in energy efficiency. Due to the composition of the Mexican Iron and Steel production, we considered the share of scrap input in the iron and steelmaking as the most representative structural factor. We plot the actual SEC and an aggregate "best practice" SEC, which is calculated on the basis of product and process mix (PPI) and the "best practice" SEC for each product (Table 1) versus the structural factor (share of scrap input[i]).

To estimate the technical potential of the energy efficiency improvement in this industry, we calculated the difference between the actual SEC and the "best practice" SEC.

III. OVERVIEW OF PRODUCTION AND ENERGY USE IN THE MEXICAN IRON AND STEEL INDUSTRY

The Iron and Steel Industry is the most energy-consuming and energy intensive industry in the Mexican industrial sector. In 1995, this industry consumed 17.7% of the industrial sector energy (SE, 1997).

The steel production increased with an annual growth rate of 4.7% from 1970 to 1995. In the same period the primary specific energy consumption (SEC) decreased from 28.4 to 23.8 GJ/tonne of crude steel.

Within the iron making stage, the iron production has increased with an annual growth of 5.0% from 1970 to 1995. In this period, the share of production in blast furnaces and direct reduction has changed, the production of sponge iron has risen fast in last 10 years.

The next step in the manufacturing of the semifinished products is the casting. The continuous casting ratio has increased from 9.8% in 1970 to 79.8% in 1995.

Within the steel making stage, the main processes used in the Mexican Iron and Steel industry are the BOF and the EAF. The OHF production decreased since 1970 and it disappeared in 1992. In the other hand, the EAF production increased quickly especially in the last ten years like the DRI production did.

Table 2. Ironmaking Production

	1970	1975	1980	1985	1990	1995
Blast furnace						
Production[Mtonne]	1.65	2.05	3.64	3.60	3.67	4.13
[%]	70.4	66.9	66.6	67.5	56.8	51.7
Direct reduction						
Production[Mtonne]	0.62	0.91	1.64	1.50	2.53	3.67
[%]	26.4	29.9	30.0	28.2	39.1	46.0
Ferroalloys						
Production[Mtonne]	0.08	0.10	0.19	0.23	0.26	0.19
[%]	3.2	3.2	3.4	4.3	4.1	2.3
TOTAL Production	2.34	3.06	5.46	5.32	6.45	7.99

Source: INEGI, selected years; ISII, 1997.

Table 3. Steelmaking production

	1970	1975	1980	1985	1990	1995
Open hearth furnace						
Production[Mtonne]	2.28	2.19	1.35	1.02	0.71	0.00
[%]	58.9	41.4	18.9	13.8	8.2	0.0
Basic oxygen furnace						
Production[Mtonne]	0.00	0.69	2.69	3.14	3.53	4.54
[%]	0.0	13.0	37.6	42.4	40.4	37.4
Electric arc furnace						
Production[Mtonne]	1.60	2.40	3.12	3.24	4.49	7.59
[%]	41.1	45.5	43.6	43.8	51.4	62.6
TOTAL production	3.88	5.27	7.16	7.4	8.73	12.1

Source: INEGI, selected years; ISII, 1997.

Table 4. Continuous casting and Ingot casting

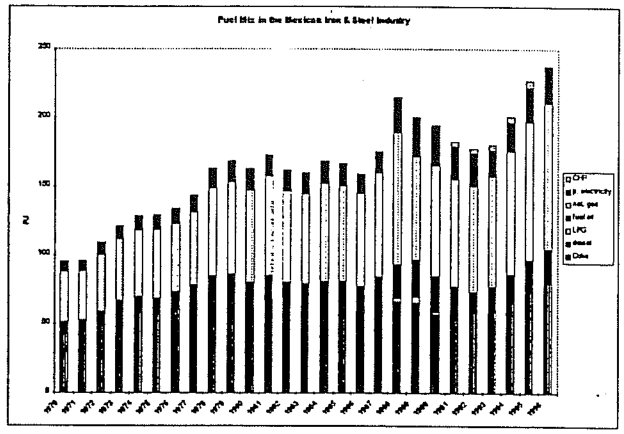
	1970	1975	1980	1985	1990	1995
Continuous casting						
Production [Mtonne]	0.4	0.7	2.1	3.8	5.5	9.6
[%]	9.8	13.3	29.3	51.1	63.6	79.8
Ingot casting						
Production [Mtonne]	3.5	4.6	5.1	3.6	3.1	2.4
[%]	90.2	86.7	70.7	48.9	36.4	20.2

Source: IISI, 1997.

Finally, the production of the hot rolled steel has increased from 63% in 1970 to 72% in 1995, while the cold rolled steel production decreased from 25% in 1970 to 12%.

Since 1982, the integrated plants uses a share of blast furnace gases and natural gas to generate electricity (PEMEX, 1985).

Figure 1. Fuel mix of the Mexican Iron and Steel Industry



The Iron & Steel industry fuel mix can be explained by the iron & steel making processes (Figure 1). The coke and natural gas are used to transform the iron ore into iron, and their consumption has grown as the BF pig iron and the DRI production has increased. The fuel oil is used for firing and heating. Electricity is mainly used in the EAF, but also in the rolling stages, the oxygen production for the BOF, transportation, etc.

IV. RESULTS

IV.1 SEC decomposition analysis

The relative influences of changes in structure and efficiency on specific energy consumption in iron and steel making are presented in Table 5. The decline of 16% in the SEC of the Mexican Iron and Steel industry between 1970 and 1995 was accounted mainly to energy efficiency improvements: the complete substitution of OH furnaces by BO and EA furnaces in the integrated plants and the rapid increase of the continuous casting (from 9.8% to 79.8%).

Table 5. Changes of the Specific Energy Consumption between 1970 and 1995 (relative changes in percentages)

Period	SEC_p (1970) [GJ/tcs]	Structure [GJ/tcs]	Efficiency [GJ/tcs]	SEC_p (1995) [GJ/tcs]
1970-1995	28.4	1.6 (5%)	-5.9 (-21%)	23.8 (-16%)

Structural changes also influenced the SEC. Although the increase of the scrap input and the growth of the EAF production in the steel making, the main input to the EAF is DRI rather than scrap due to its higher cost. This DRI production requirement leads to a higher energy consumption.

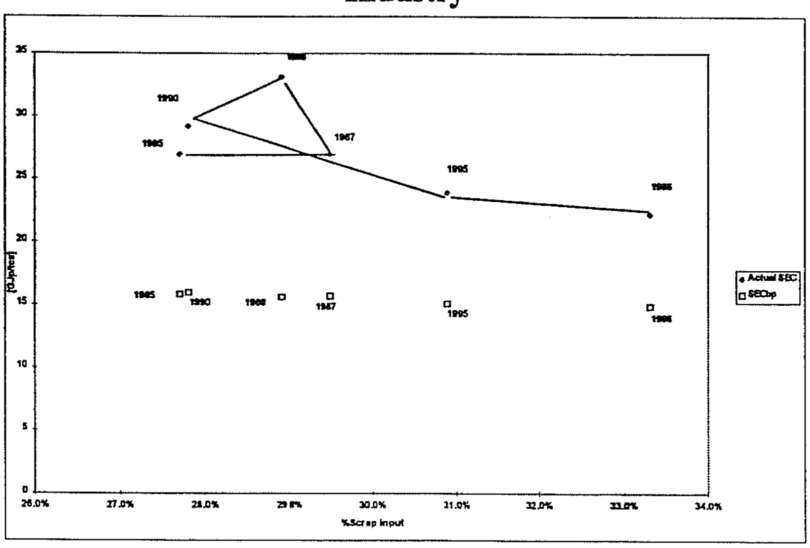
IV.2 International comparisons structure / efficiency analysis

In order to examine moreover the changes in the SEC using the structure/efficiency analysis, we compared the actual SEC and the best practice SEC of the Mexican Iron and Steel industry from 1985 to 1996 due to the scrap consumption data availability (Figure 2). During this period, improvements on energy efficiency and changes in the process and product mix led to an important decrease of the SEC. These energy efficiency improvements are: the closure of the OHF capacity, an increase of continuous casting ratio (51.1% in 1985 to 79.8% in 1995) and an increase of the utilization of blast furnace gas for the electricity generation for the uses of the own plant. Within the process and product mix changes, the secondary steelmaking production with DRI-EAF and scrap-EAF grew fast, the specific scrap consumption increased (0.28 to 0.3 tonne of scrap/tonne of primary crude steel) and the cold rolled steel production declined.

The increase of the SEC between 1987 to 1990 was probably due to the replacement of the OHF production by the BOF production because less share of scrap can be introduced in the BOF. As the scrap input declined from 29.5% in 1987 to 27.8% in 1990, the requirement of pig and DR iron increased.

Comparing the actual SEC and the best practice SEC of the Mexican Iron and Steel Industry in 1995, the estimated potential for energy efficiency using the "best practice technology" in 1995 was about 37.7%.

Figure 2. Specific Energy Consumption of the Mexican Iron and Steel Industry



Finally we compare the Mexican iron and steel industry with five of the largest world crude steel producers to understand the trends of this industry. Due to the data availability, these selected countries are: Japan, United States, Germany, Brazil and France. The aggregated SEC and best practice SEC for the iron and steel industry of these countries were calculated and presented in Table 6 and Figure 3.

It is important to remark that the differences between Mexico and the compared countries are the high share of DRI-EAF production and the low share of scrap input in the steelmaking process.

The low SEC of countries like Japan, France and West Germany in 1990 were due to the closure of OHF and the fast penetration of continuous casting in the early 1980s (Worrell, 1997). Specific energy efficiency measures for Germany like recovery of BOF gases; increased use of pellets as blast furnace feed; an increase electricity production using recovered blast furnace gases; and heat recovery in EAF, sinter plants and furnaces are the reasons of its low SEC (Worrell, et.al. 1997). While Japan's low SEC was due mainly to product mix changes: low share of cold rolled products, decrease of scrap input at the BO furnaces, and pig iron imports. In the other hand, Brazil had a high SEC because its high pig iron production; in 1990, Brazil exported a large quantity of pig iron.

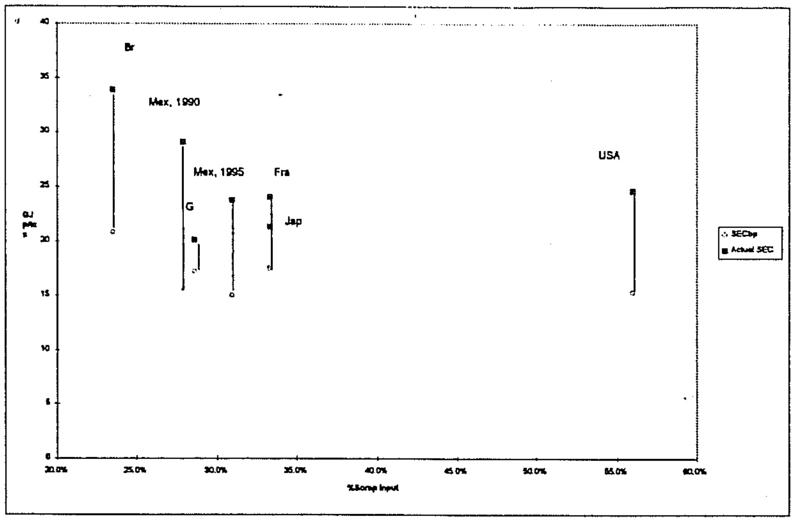
The most distinguishing characteristics of U.S. iron and steel industry is its high scrap input in its EAF steelmaking production that is also high. Although its SEC is not as low as other OECD countries because of the slow penetration of new technologies in the iron and steelmaking and casting processes (Worrell and Moore, 1997).

Table 6. Main characteristics of the iron and steel making processes and aggregated SEC for the selected countries in 1990

	Pig iron [Mtonne]	Crude steel [Mtonne]	Share of BOF [%]	Share of OHF [%]	Share of EAF [%]	Scrap input [%]	SEC [GJ/tcs]
Japan	80.2	110.3	69	0	31	33	21.3
France	14.4	19.0	66	0	34	33	24.1
Germany	30.1	38.4	78	2	20	29	20.2
United States	50.1	89.7	37	4	59	56	24.7
Brazil	21.1	20.6	26	0	74	23	33.9
Mexico (1990)	3.7	8.7	52	8	40	27	29.1
Mexico (1995)	4.1	12.1	37	0	63	31	24.6

Source: IISI, 1996; Worrell, et. al. 1997b.

Figure 3. International Comparisons of the Iron and Steel Industry



CONCLUSIONS

We describe the past trends of the Mexican iron and steel development to explain the factors that influenced the SEC reduction during the analyzed period. The closure of the OHF capacity and the penetration of the continuous casting are the most important energy efficiency improvements that led to the SEC decline. Also, the most important input factor that affect the energy consumption of the iron and steel industry is the feedstock. In Mexico, the secondary steel making production has increased fast in the last few years, however, due to the high cost of the scrap, and the natural gas and iron ore availability, the DRI is the main input to the EAF. Comparing to other countries with similar scrap input, this characteristic results in a higher SEC.

The estimated technical potential for energy efficiency using "the best practice technology" in 1995 was about 37.7%. Comparing to the selected low SEC countries, the following energy efficiency measures can be recommended: Recovery of BOF gases; increase of heat recovery in EAF, sinter plants and furnaces; increase of pellets as blast furnace feed; increase of electricity production using the recovered blast furnace gases; optimization of the molten iron input at the EAF; introduction of thin slab casting; good housekeeping, etc.

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[i] The share of scrap input is calculated as the ratio of the total consumption of scrap divided by the total steelmaking inputs (total scrap, pig iron, sponge iron and imported iron)
Total consumption of scrap is calculated as the summing of the scrap used in blast furnaces, BO, OH and EA furnaces.